

# Time-variable gravity field recovery from kinematic positions of Low Earth Orbiting satellites

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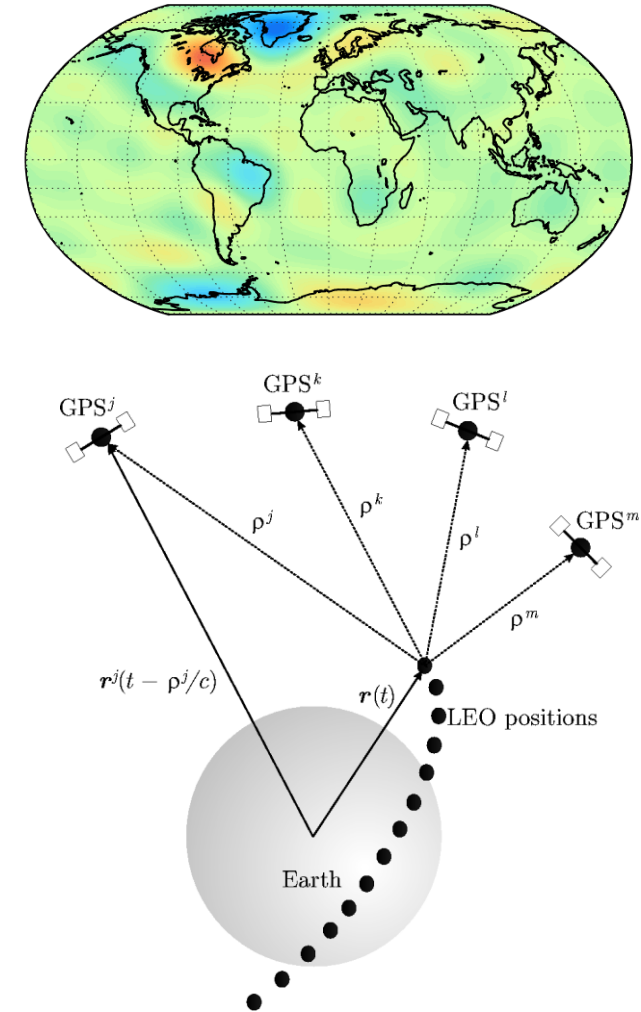
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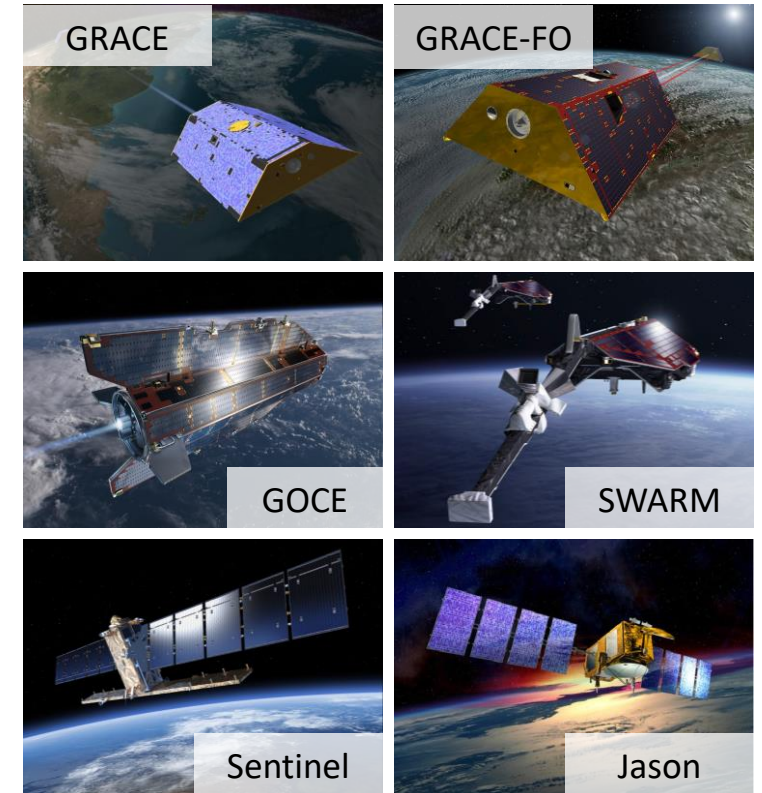
# Introduction

- The Earth's time-variable gravity field
  - Provides important information for monitoring changes in the Earth's system
  - Dedicated satellite missions like GRACE/-FO use ultra-precise K-Band data (inter-satellite ranging) to derive time series of monthly gravity field solutions
  - In addition: any Low Earth Orbiting (LEO) satellite equipped with an on-board GPS receiver may also serve as a gravity field sensor
- Gravity field recovery from kinematic LEO positions
  - GPS-based kinematic LEO positions are purely geometrically determined and therefore suitable for gravity field recovery
  - Although less sensitive, this technique provides mostly uninterrupted series
  - Combined Multi-LEO gravity field solutions can take advantage of many observations and the variety of complementary orbital configurations



# GPS-based orbit and gravity field determination

- Precise orbit determination
  - GPS-based kinematic orbits are routinely processed at AIUB for various LEO satellites like GRACE/-FO, GOCE, SWARM, Sentinel, ...
  - Bernese GNSS Software with GNSS products of CODE
  - In-flight calibrated phase center variation (PCV) maps
  - Ambiguity-float and nowadays also ambiguity-fixed orbit solutions
- Gravity field processing (Celestial Mechanics Approach)
  - Kinematic LEO positions are used as pseudo-observations in a generalized orbit determination problem
  - Orbit and gravity field parameters are estimated simultaneously
  - Unmodeled forces are absorbed by empirical/stochastic parameters



Source: ESA, NASA

# Gravity field processing

- Focus of this talk: GRACE/-FO GPS-only solutions

	GRACE	GRACE-FO
Processing period	2009/01 – 2017/10	2018/06 – 2021/02
Kinematic orbit	ambiguity-float	ambiguity-fixed
Data sampling	10 s	
Initial conditions	6 orbital elements (daily)	
Empirical parameters	-	
Stochastic parameters	Piecewise constant accelerations (15 min)	
Accelerometer data	Yes / Bias and Scaling factors (daily)	
Gravity field coefficients	d/o 90 (monthly)	

- Further used GPS-only solutions

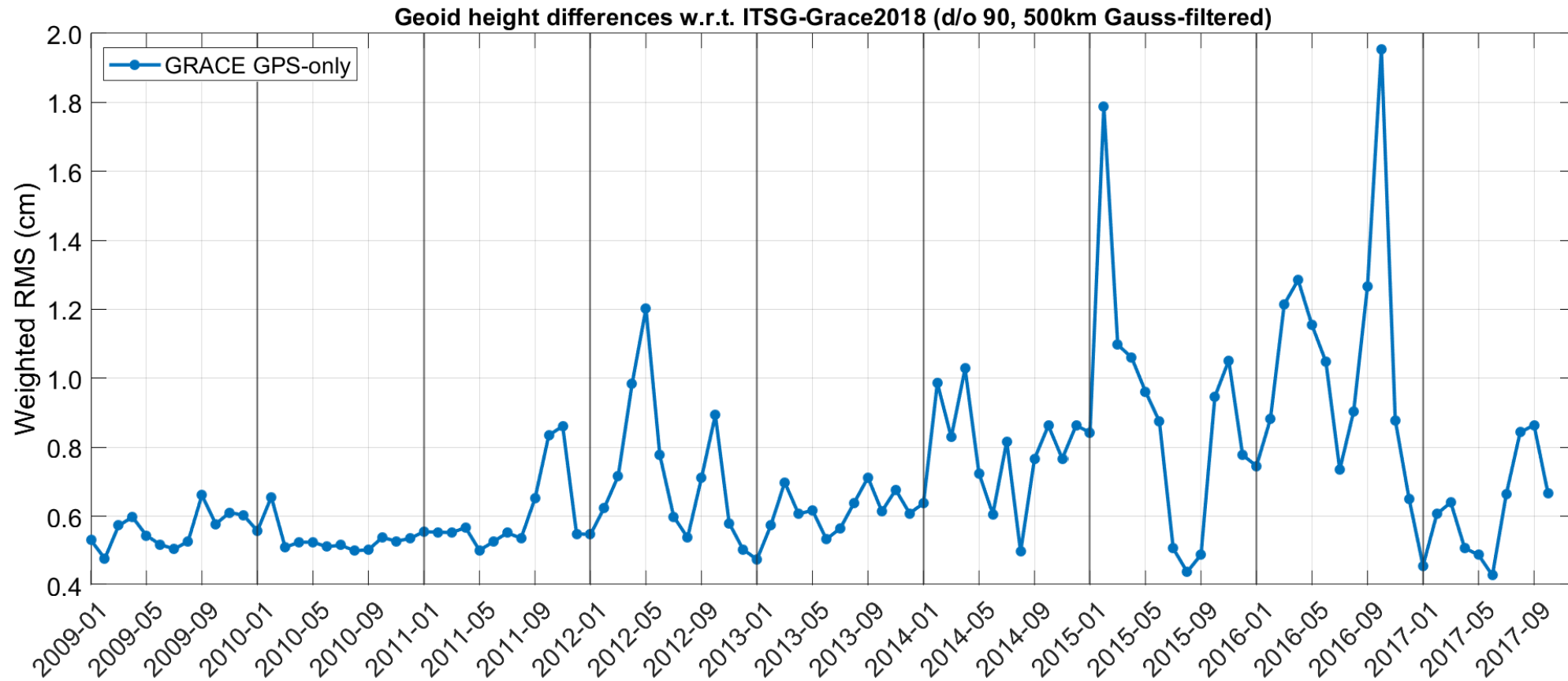
GOCE (Arnold et al. 2021)	SWARM (Dahle et al. 2017)
2009/11 – 2013/10	2013/12 – 2020/12
ambiguity-float	ambiguity-float
1 s	10 / 5 s
6 orbital elements (daily)	6 orbital elements (daily)
Constant and 1/per rev accelerations (daily)	Constant accelerations (daily)
Pseudo-stochastic pulses (6 min)	Piecewise constant accelerations (15 min)
Yes / –	– / –
d/o 120 (monthly)	d/o 40, 70 (monthly)

- Monthly ITSG-Grace2018 / ITSG-Grace\_op solutions are used as reference ([Mayer-Gürr et al. 2018](#))

# GRACE GPS-only gravity field solutions

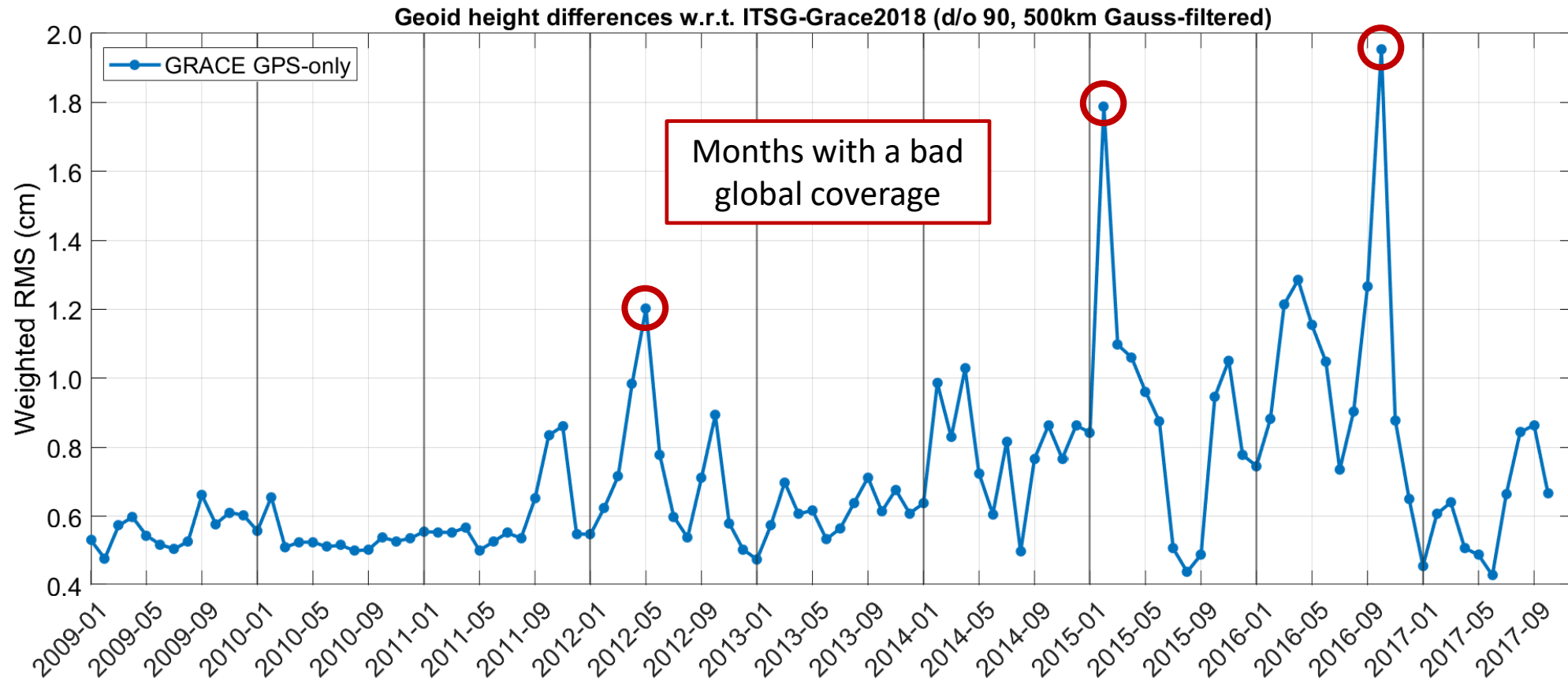
# GRACE GPS-only gravity field solutions

- Quality of monthly GRACE GPS-only gravity field solutions



# GRACE GPS-only gravity field solutions

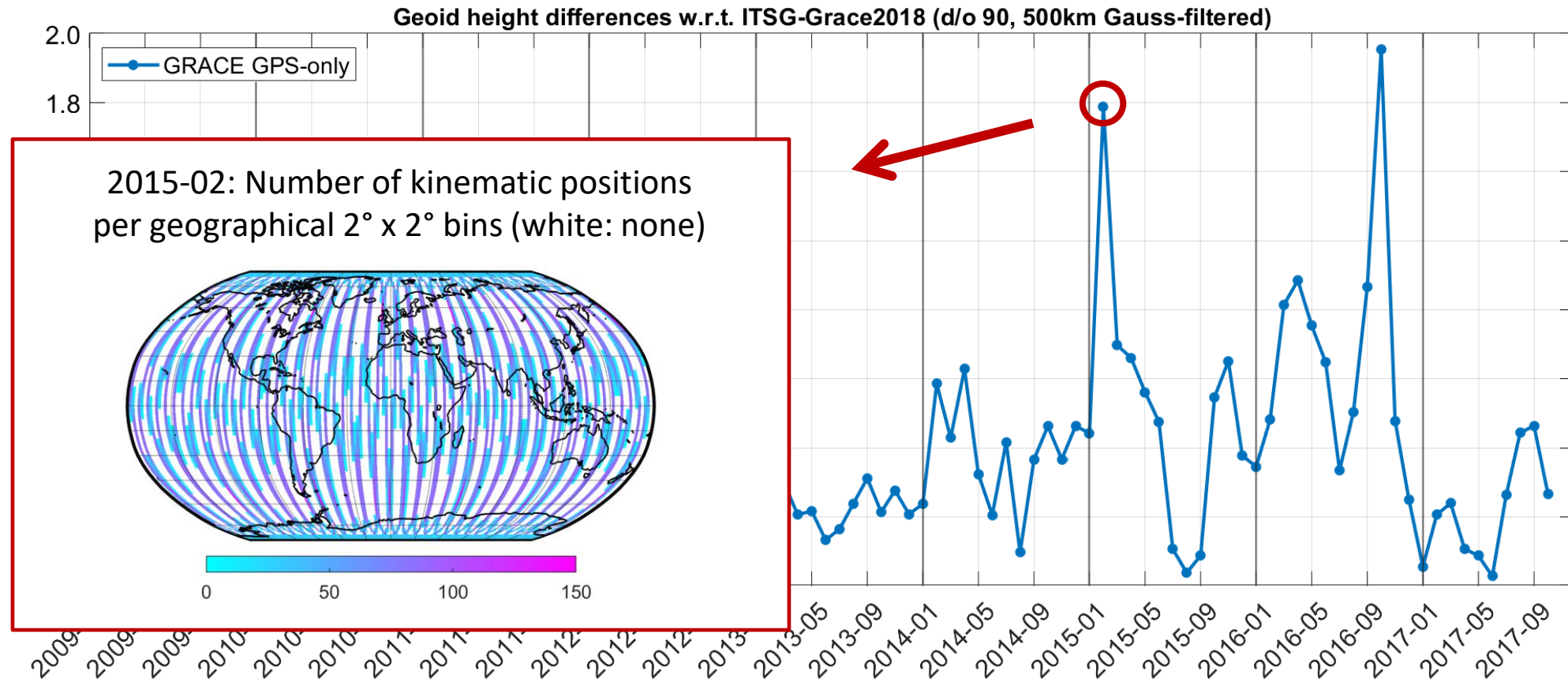
- Quality of monthly GRACE GPS-only gravity field solutions





# GRACE GPS-only gravity field solutions

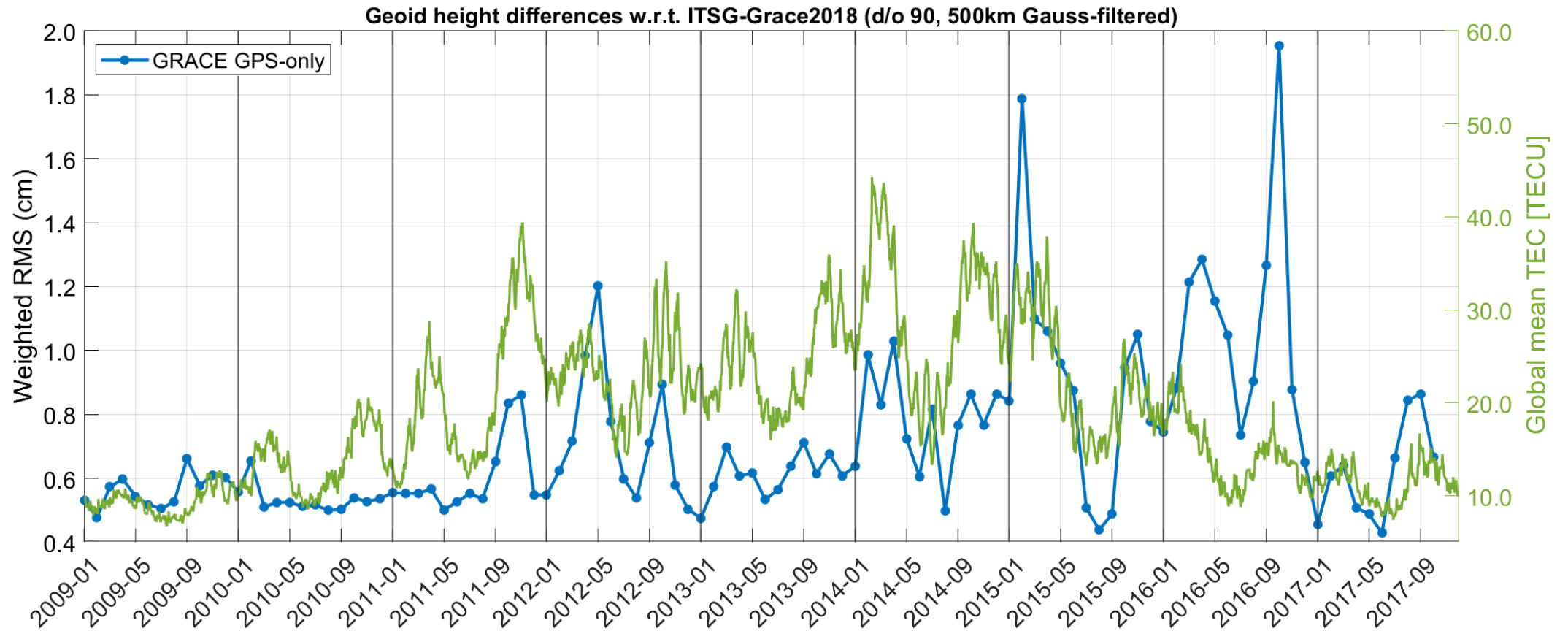
- Quality of monthly GRACE GPS-only gravity field solutions





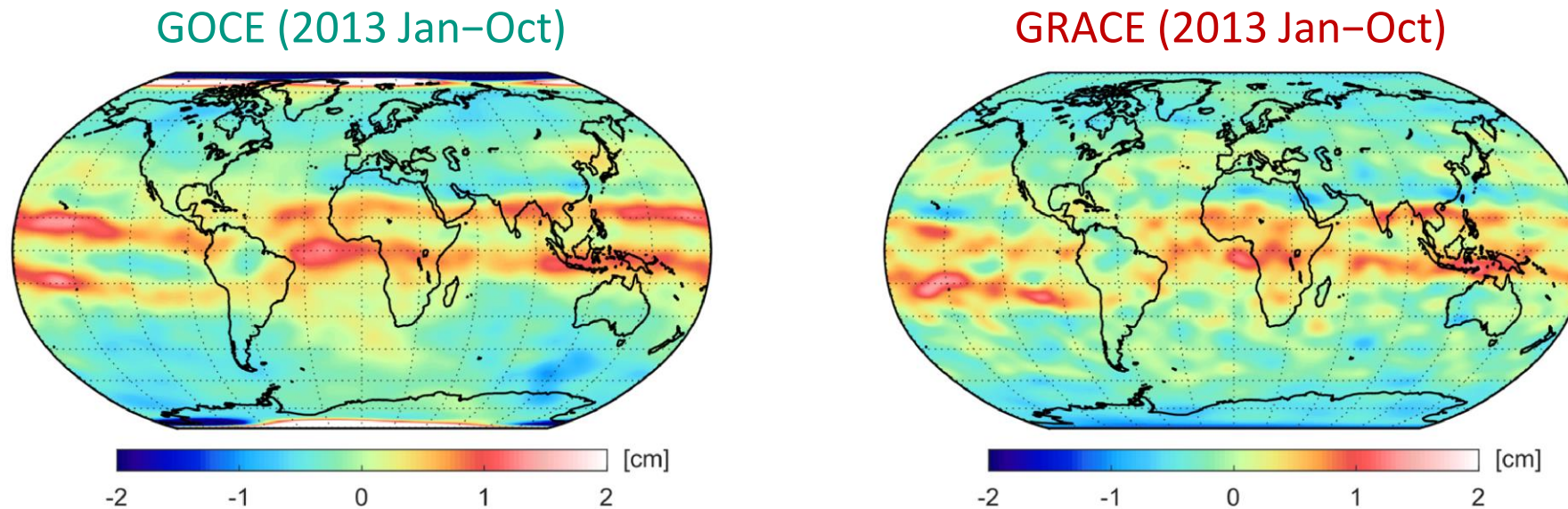
# GRACE GPS-only gravity field solutions

- Correlation with the ionospheric activity represented by the global mean total electron content (TEC)



# Effects of ionospheric disturbances

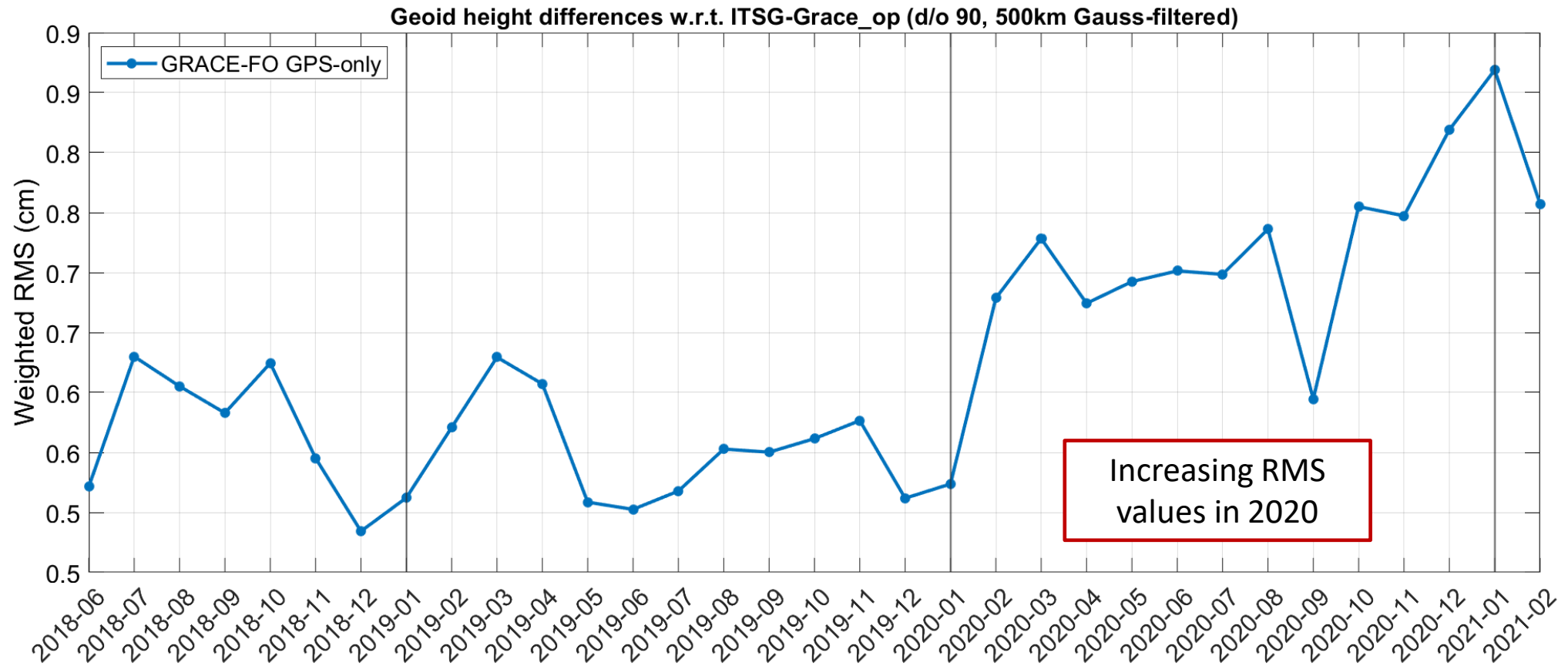
- Degradation of kinematic positions directly propagates into GPS-only gravity field solutions
- Artifacts along the geomagnetic equator, known from GOCE / SWARM, are also visible for GRACE



# GRACE-FO GPS-only gravity field solutions

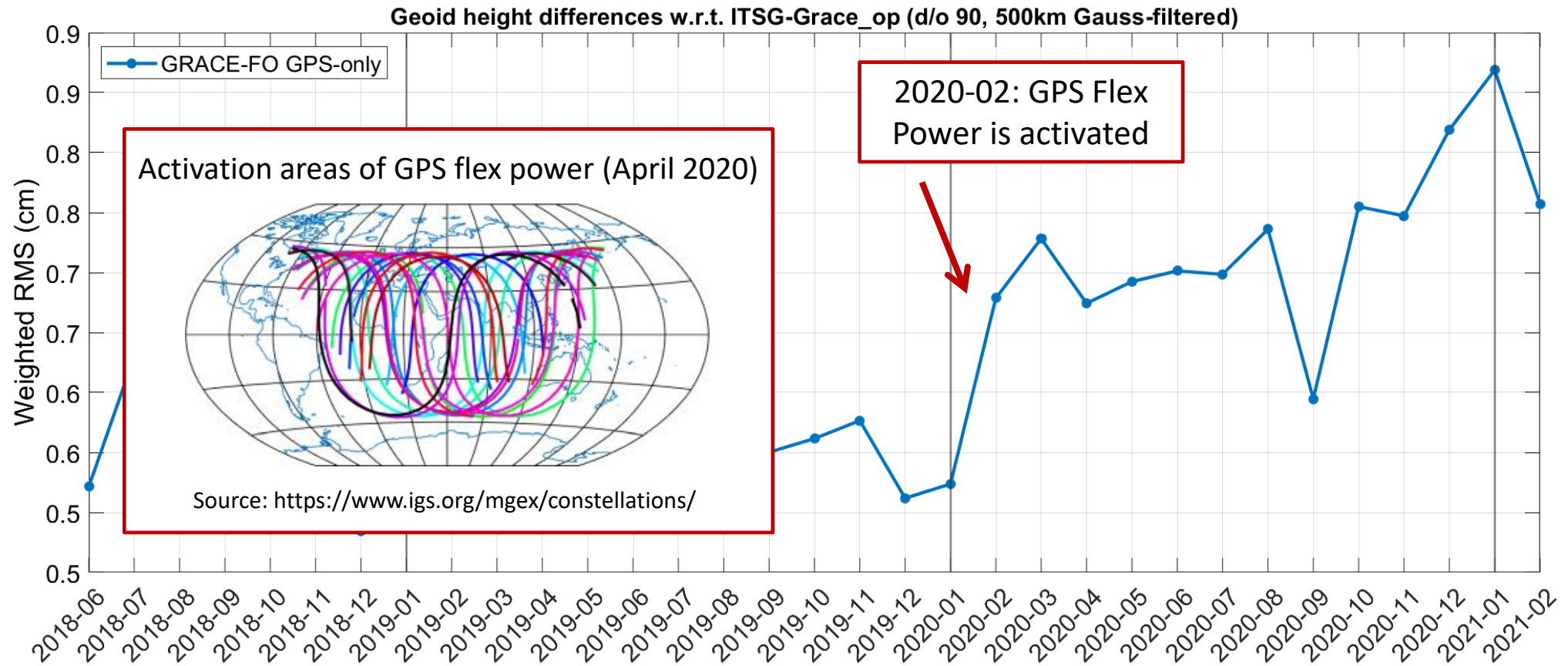
# GRACE-FO GPS-only gravity field solutions

- Quality of monthly GRACE-FO GPS-only gravity field solutions



# GRACE-FO GPS-only gravity field solutions

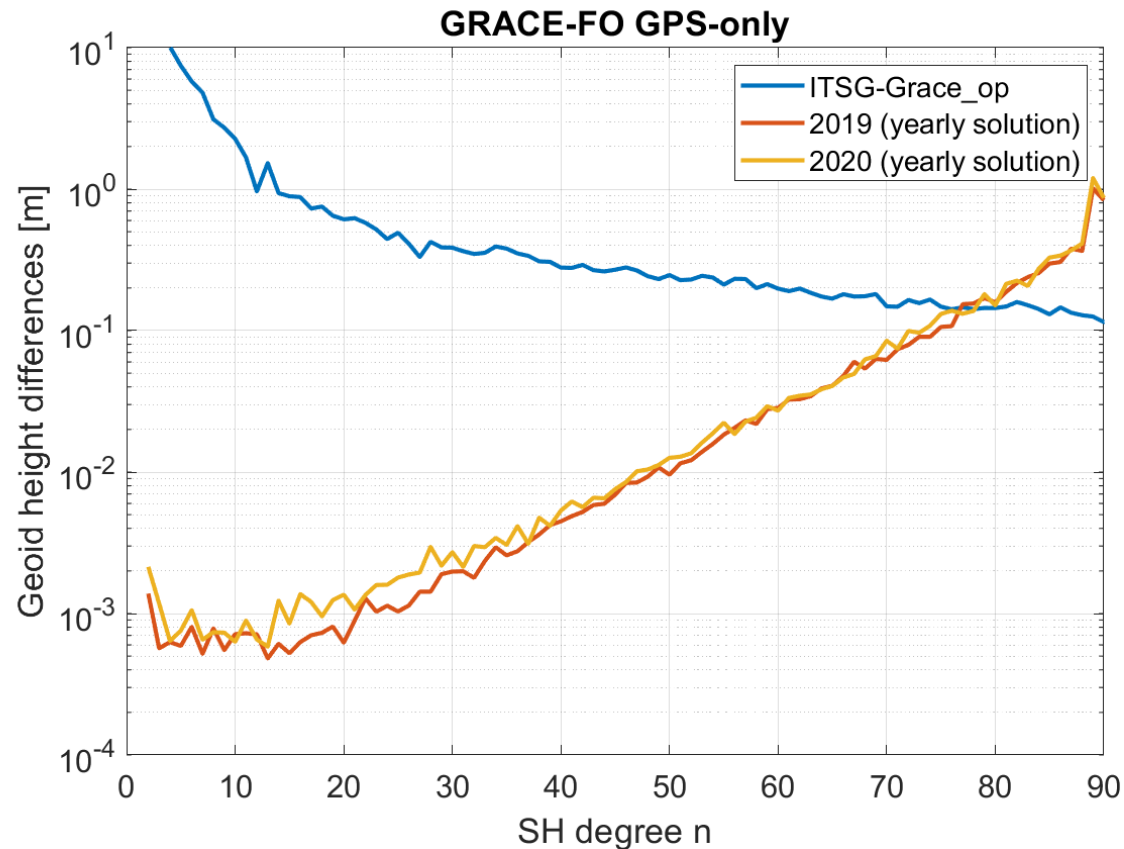
- Activated GPS Flex Power affects the orbit and gravity field quality (under investigation)





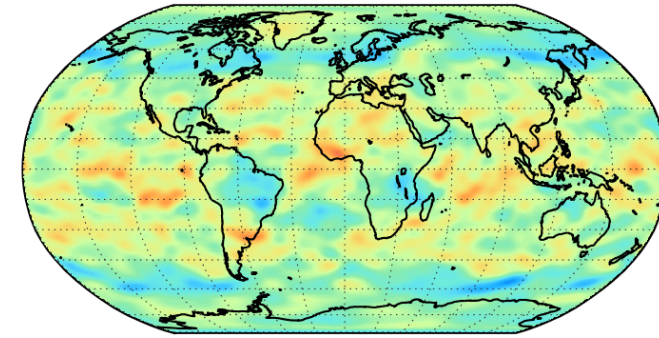
# GRACE-FO GPS-only gravity field solutions

- Comparison of accumulated yearly solutions for 2019 and 2020

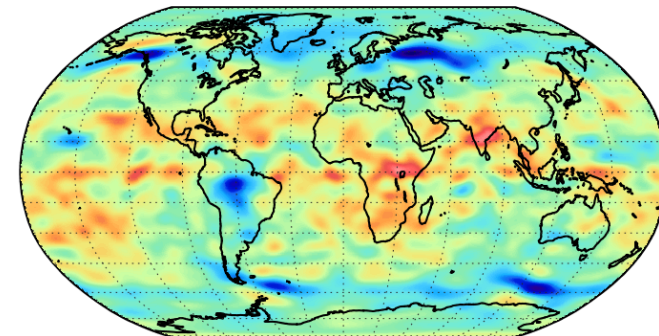


Geoid height differences

2019



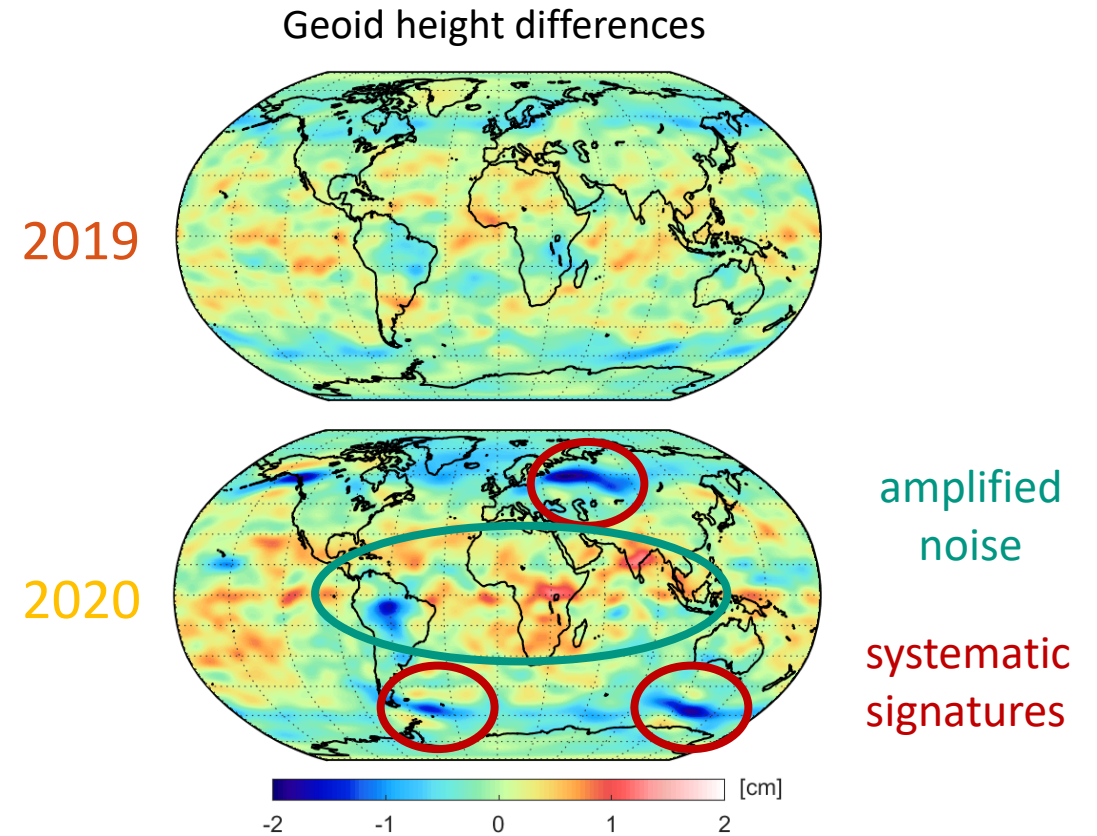
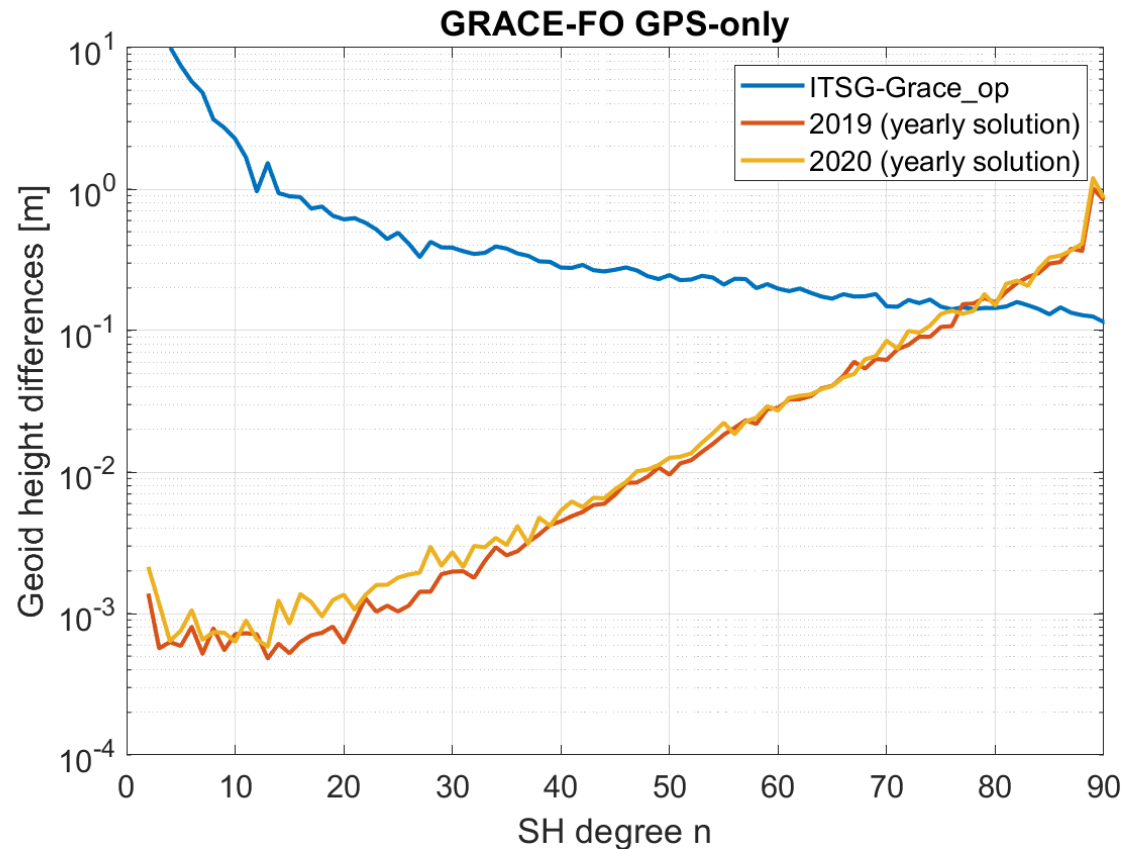
2020



-2 -1 0 1 2 [cm]

# GRACE-FO GPS-only gravity field solutions

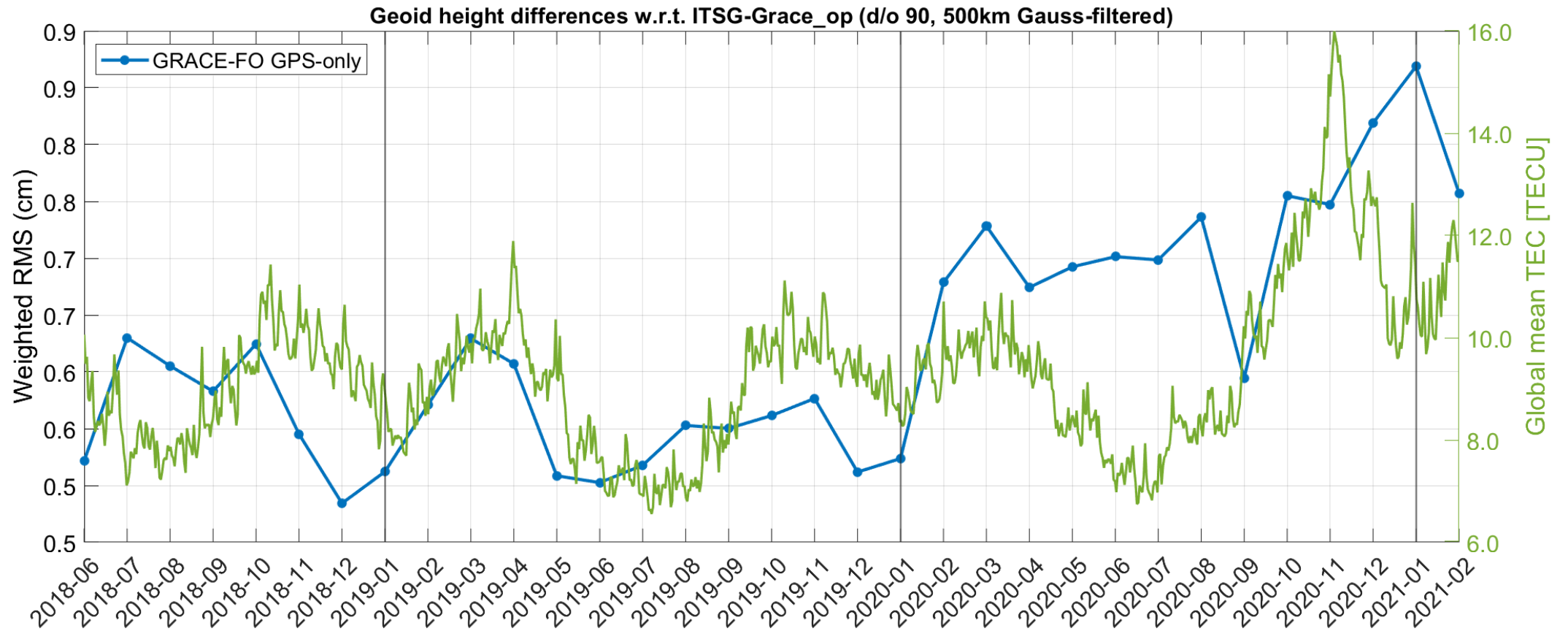
- Comparison of accumulated yearly solutions for 2019 and 2020





# GRACE-FO GPS-only gravity field solutions

- Correlation with TEC values might also be seen for GRACE-FO (but much lower ionospheric activity)

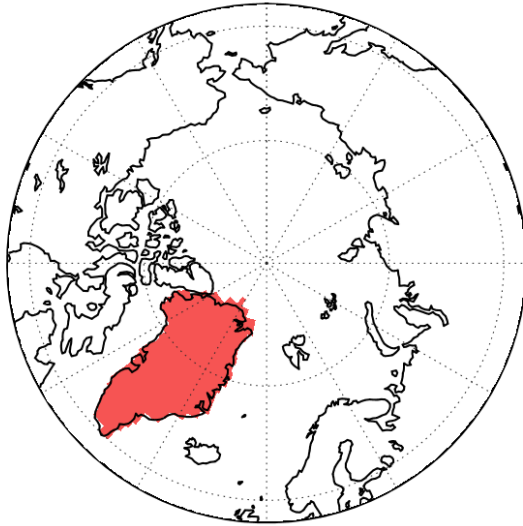


# Evaluation of mass trends and changes

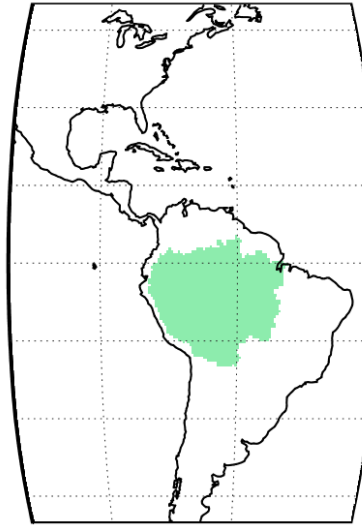
# Evaluation of mass trends and changes

- Time series of monthly GPS-only solutions are used for the evaluation of mass trends and changes
- Analysis of mean equivalent water height (EWH) values averaged over selected regions

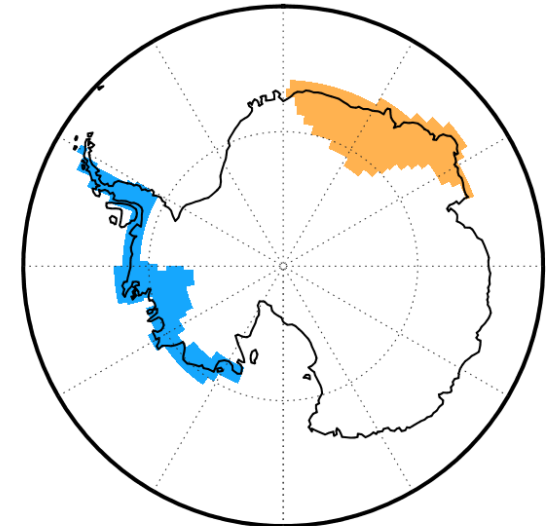
Greenland



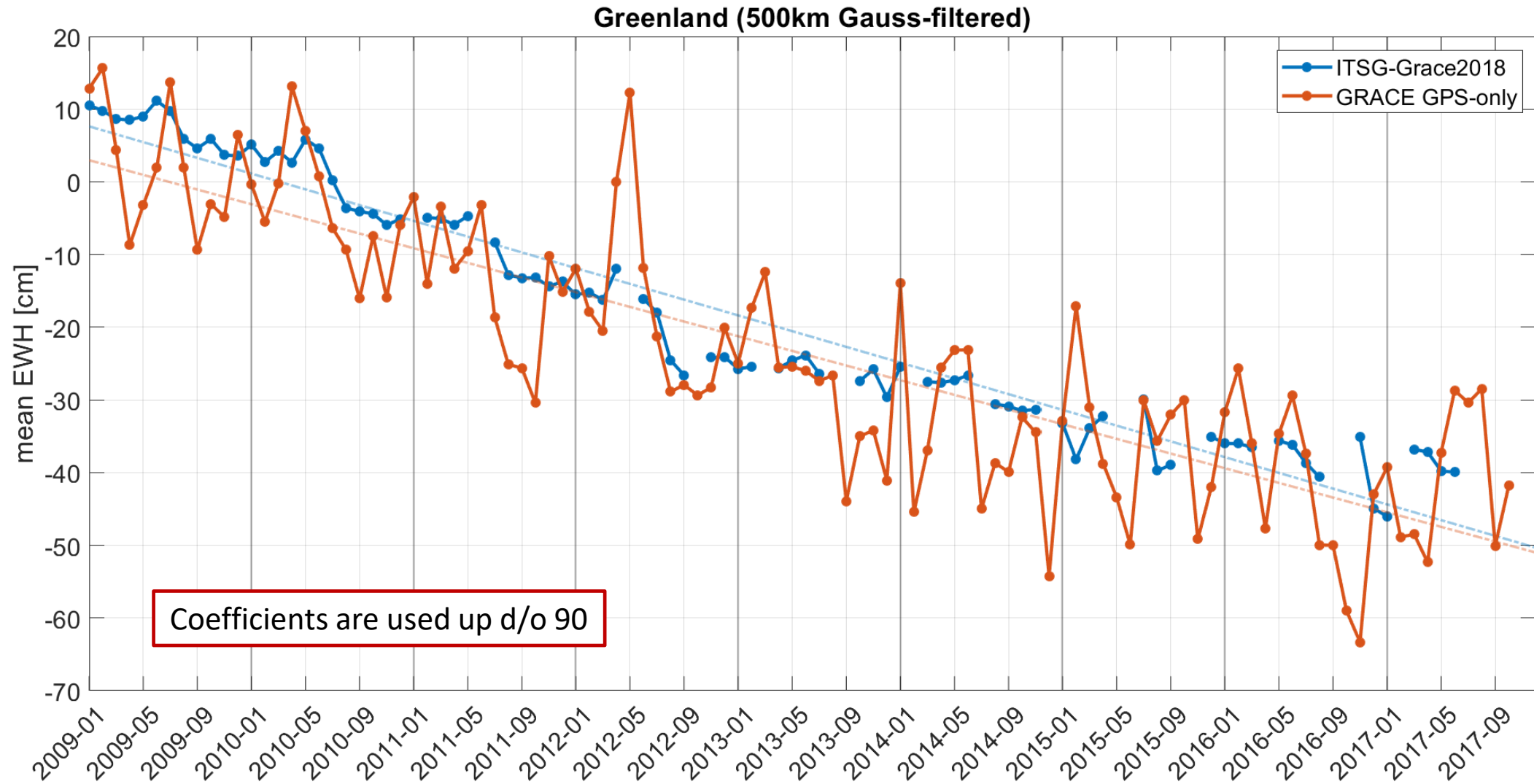
Amazon river basin



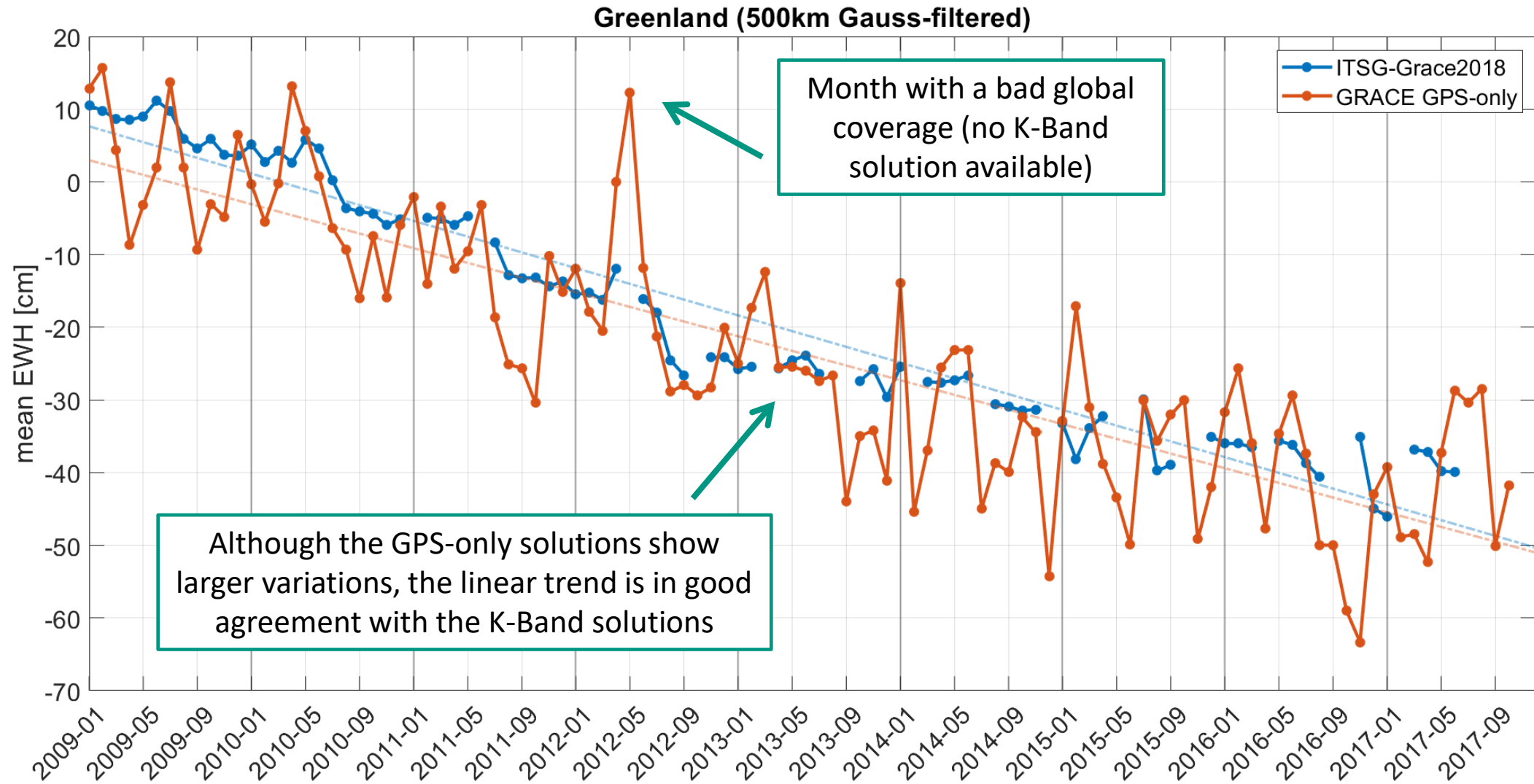
West/East-Antarctica



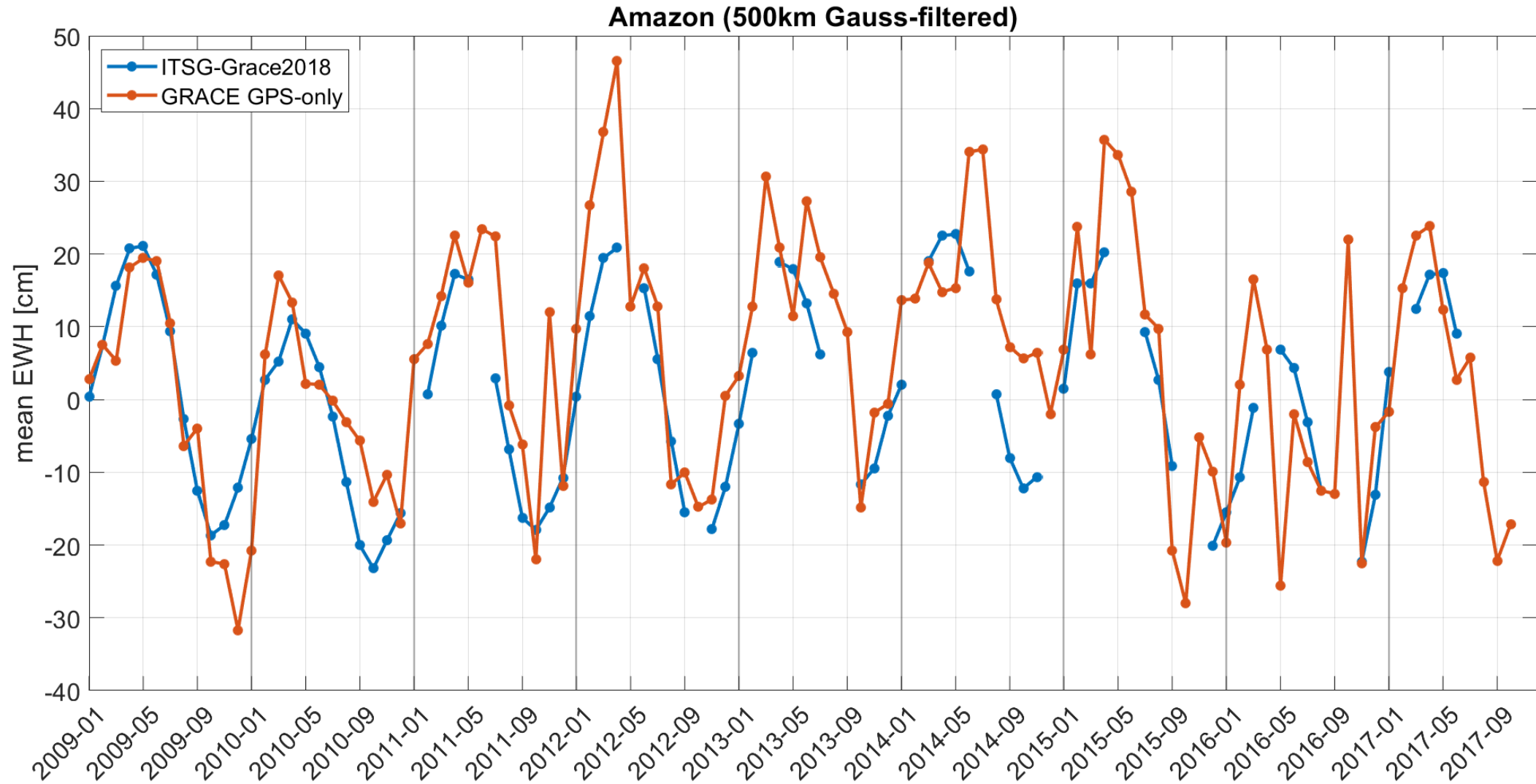
# Evaluation of mass trends and changes: GRACE GPS-only



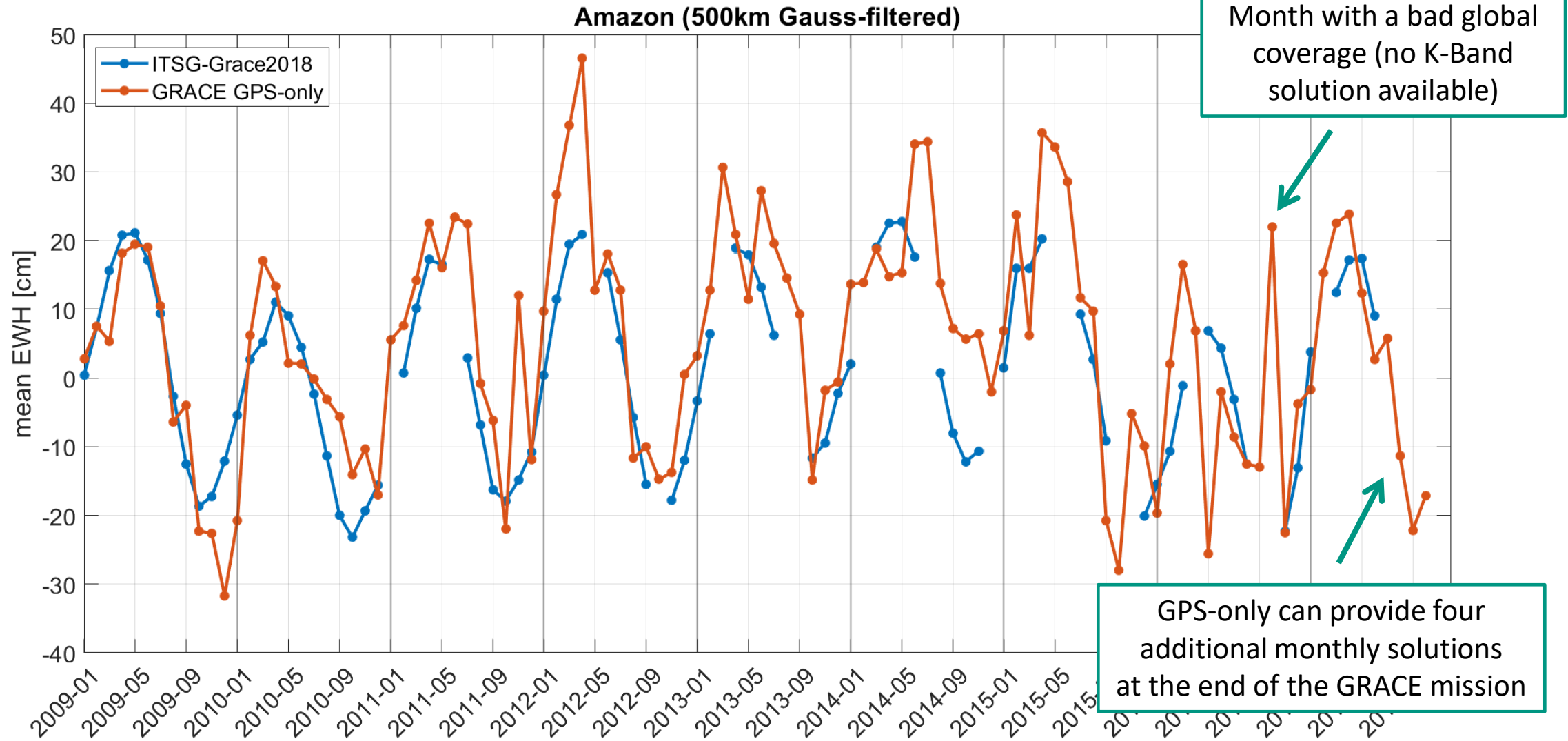
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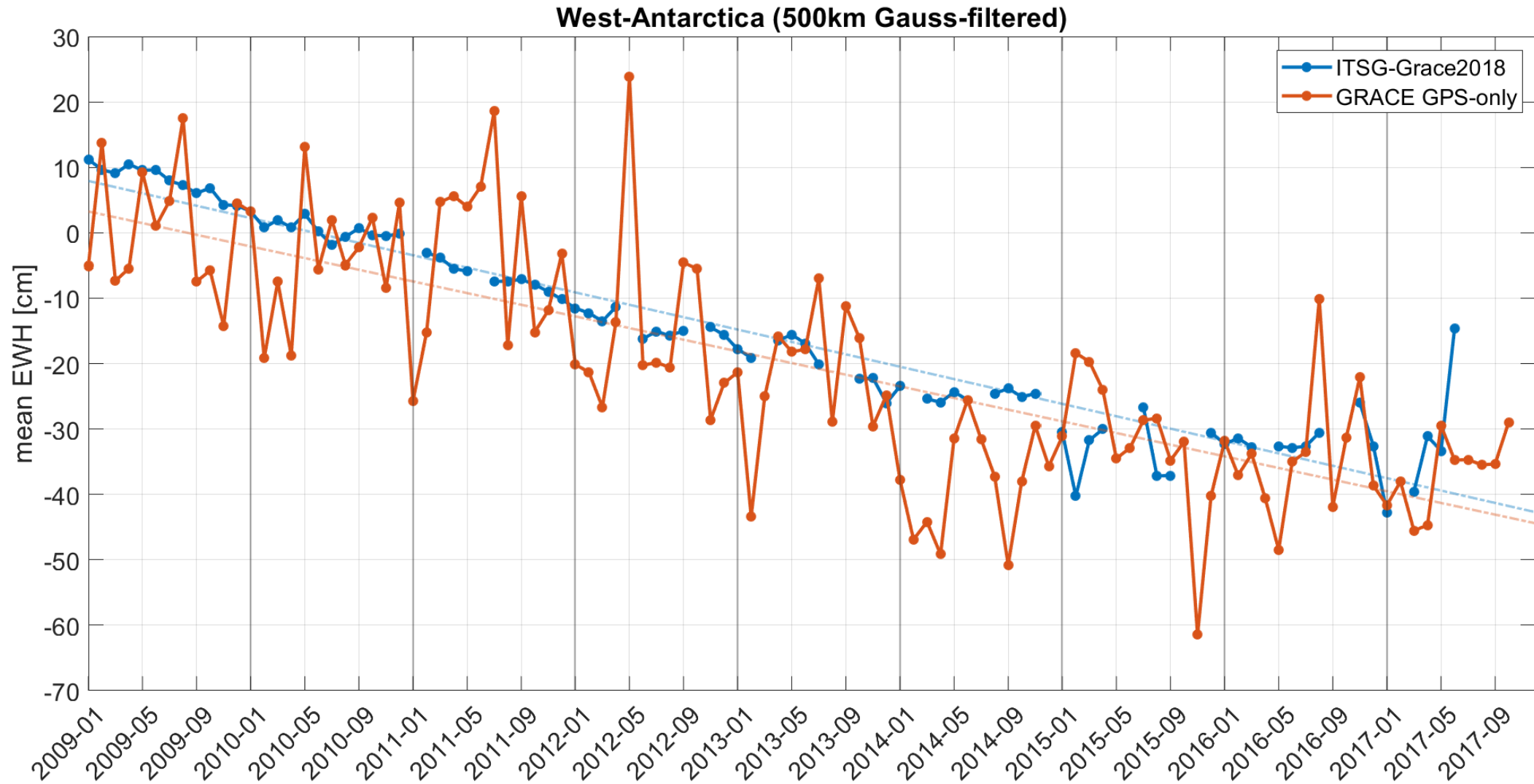


# Evaluation of mass trends and changes: GRACE GPS-only

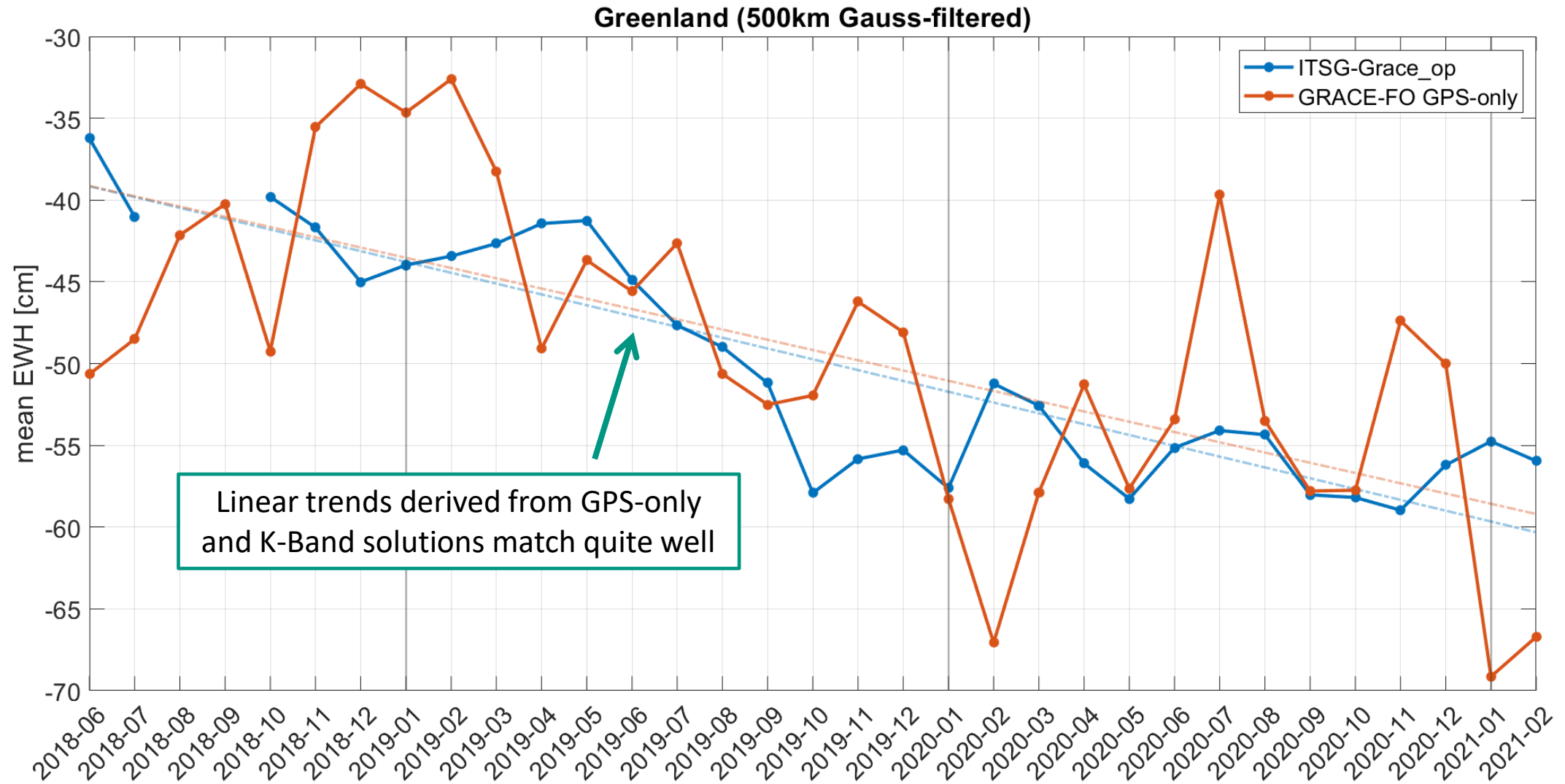




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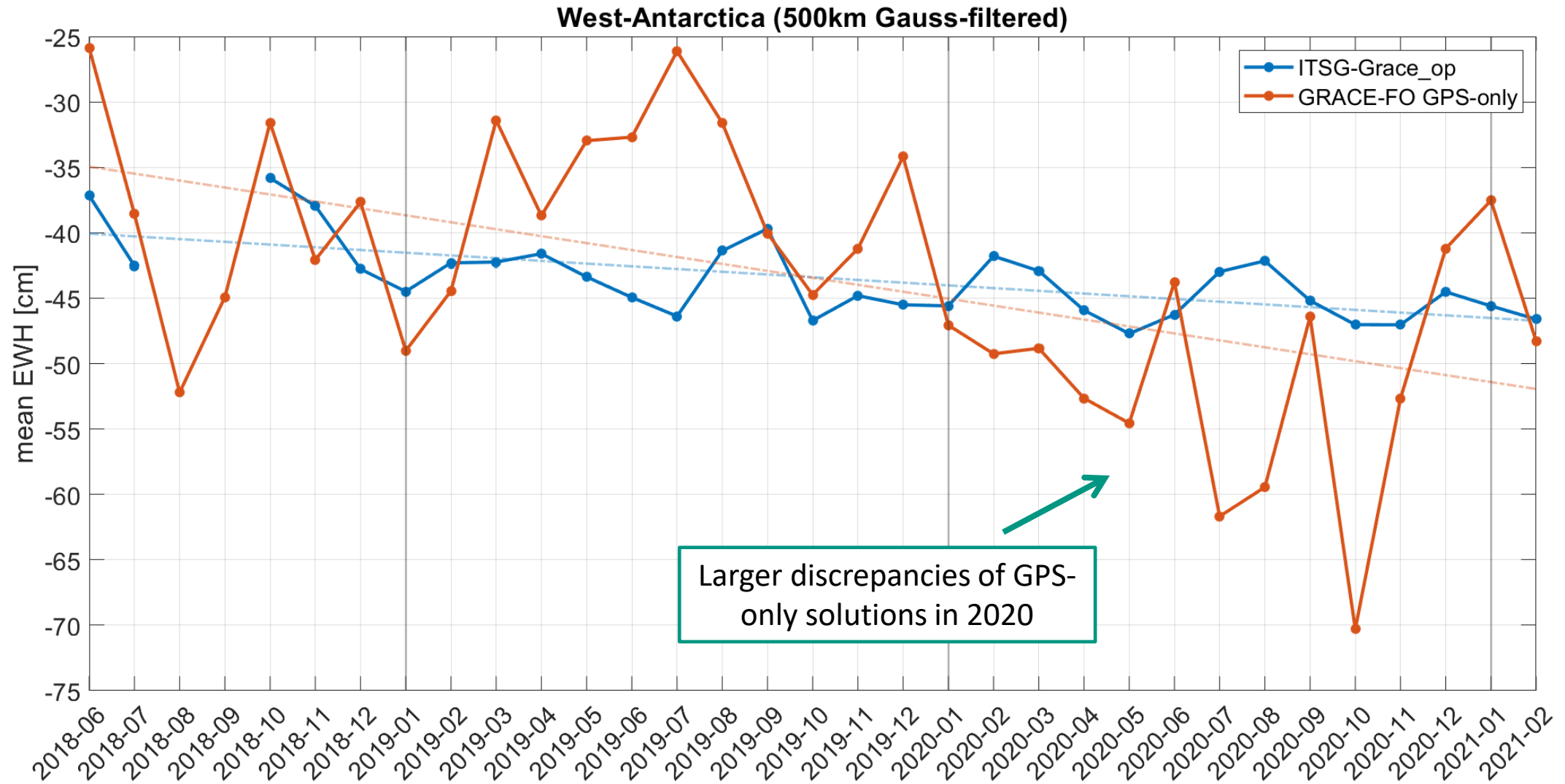
# Evaluation of mass trends and changes: GRACE-FO GPS-only



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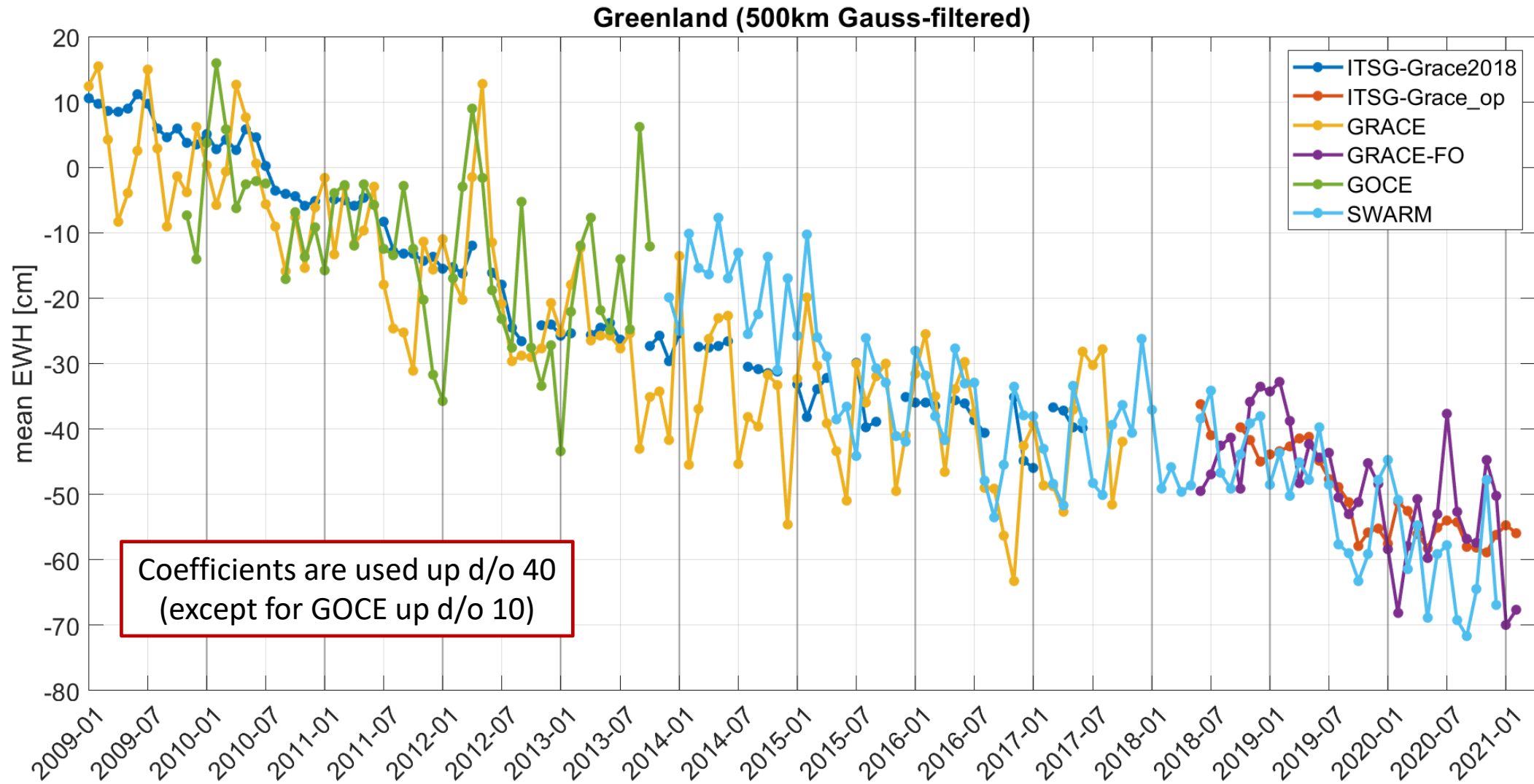


# Evaluation of mass trends and changes: GRACE-FO GPS-only

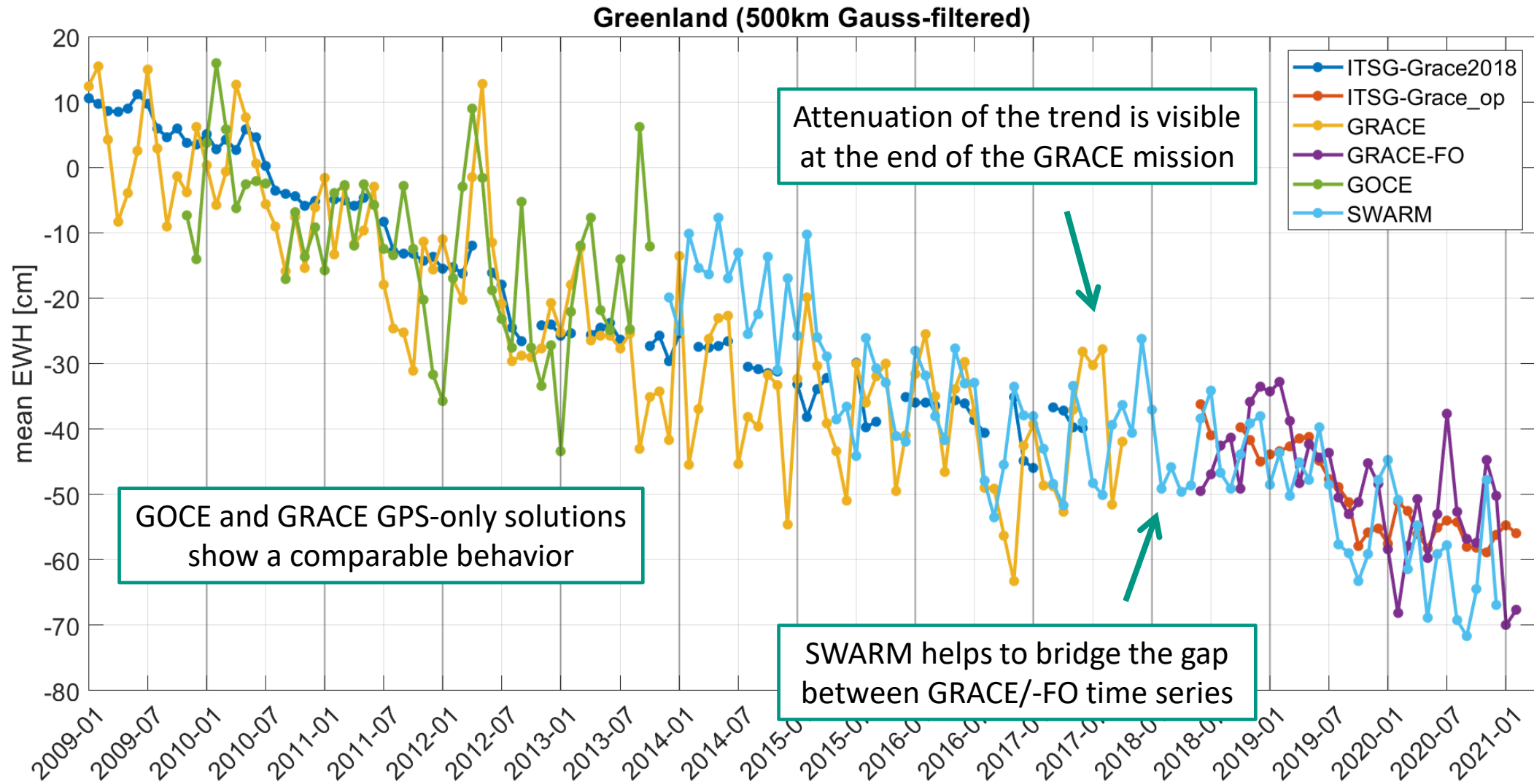


# Comparisons to time series of other LEOs

# Evaluation of mass trends and changes: Comparison to other LEOs

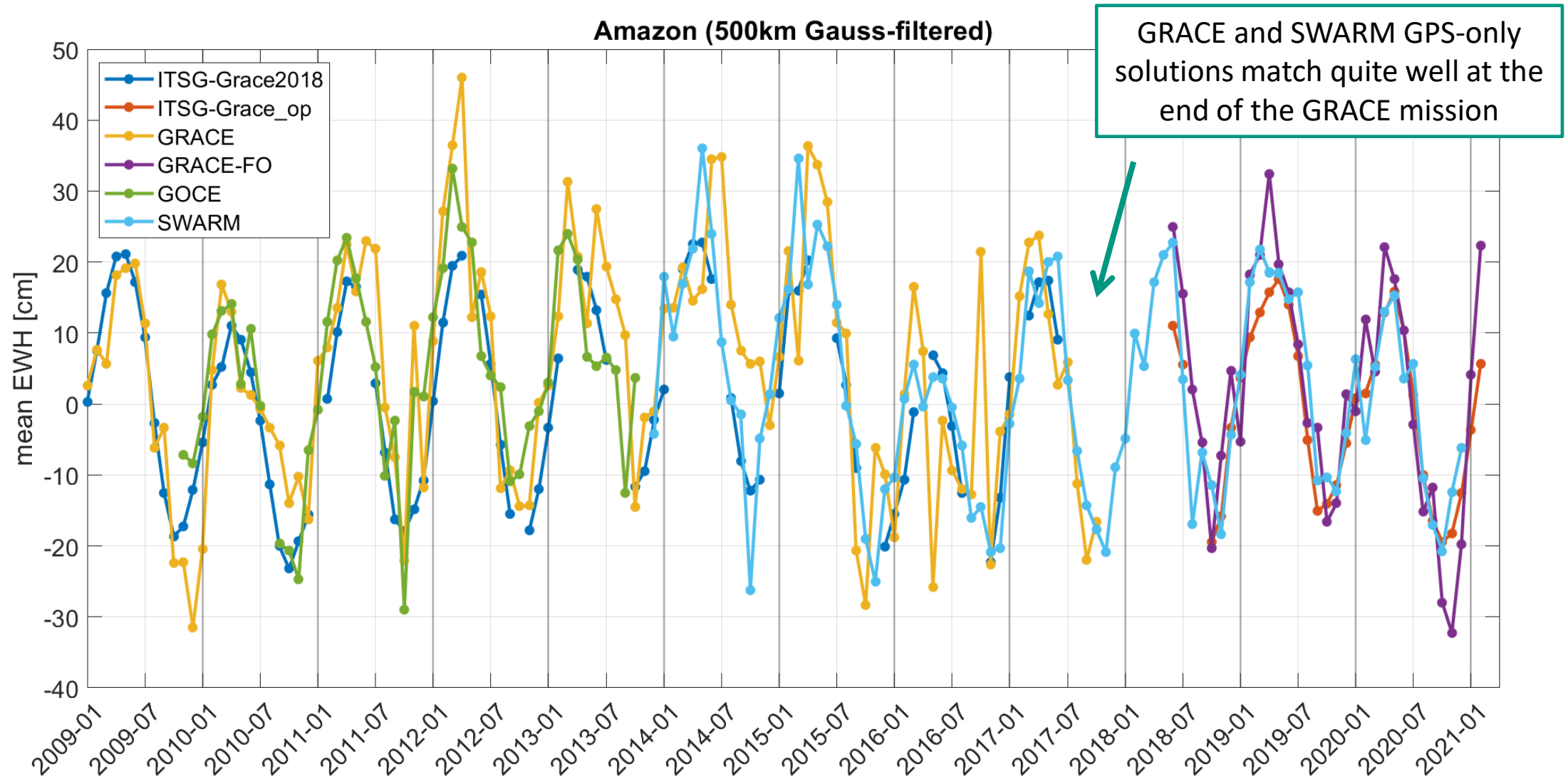


# Evaluation of mass trends and changes: Comparison to other LEOs

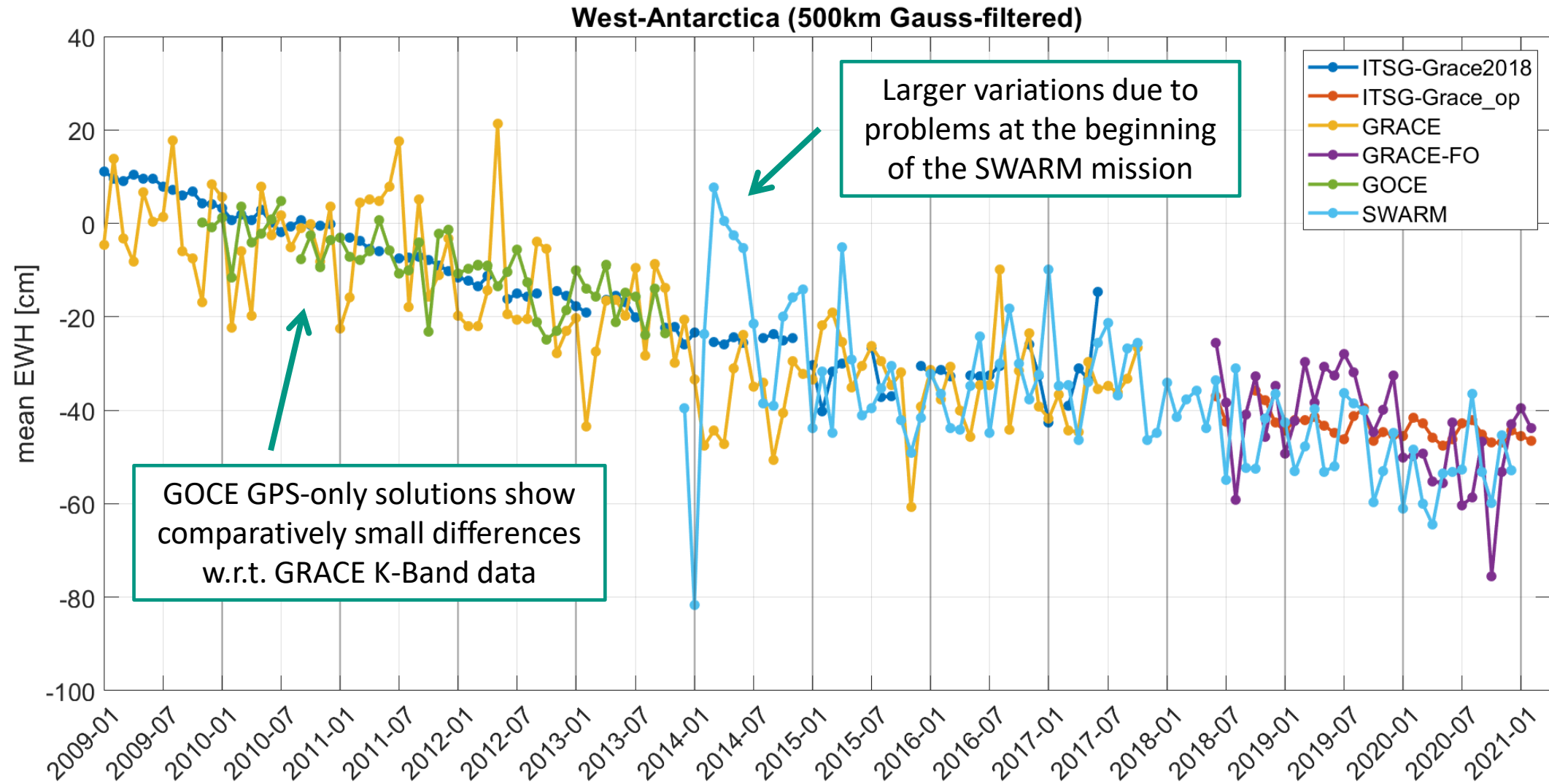




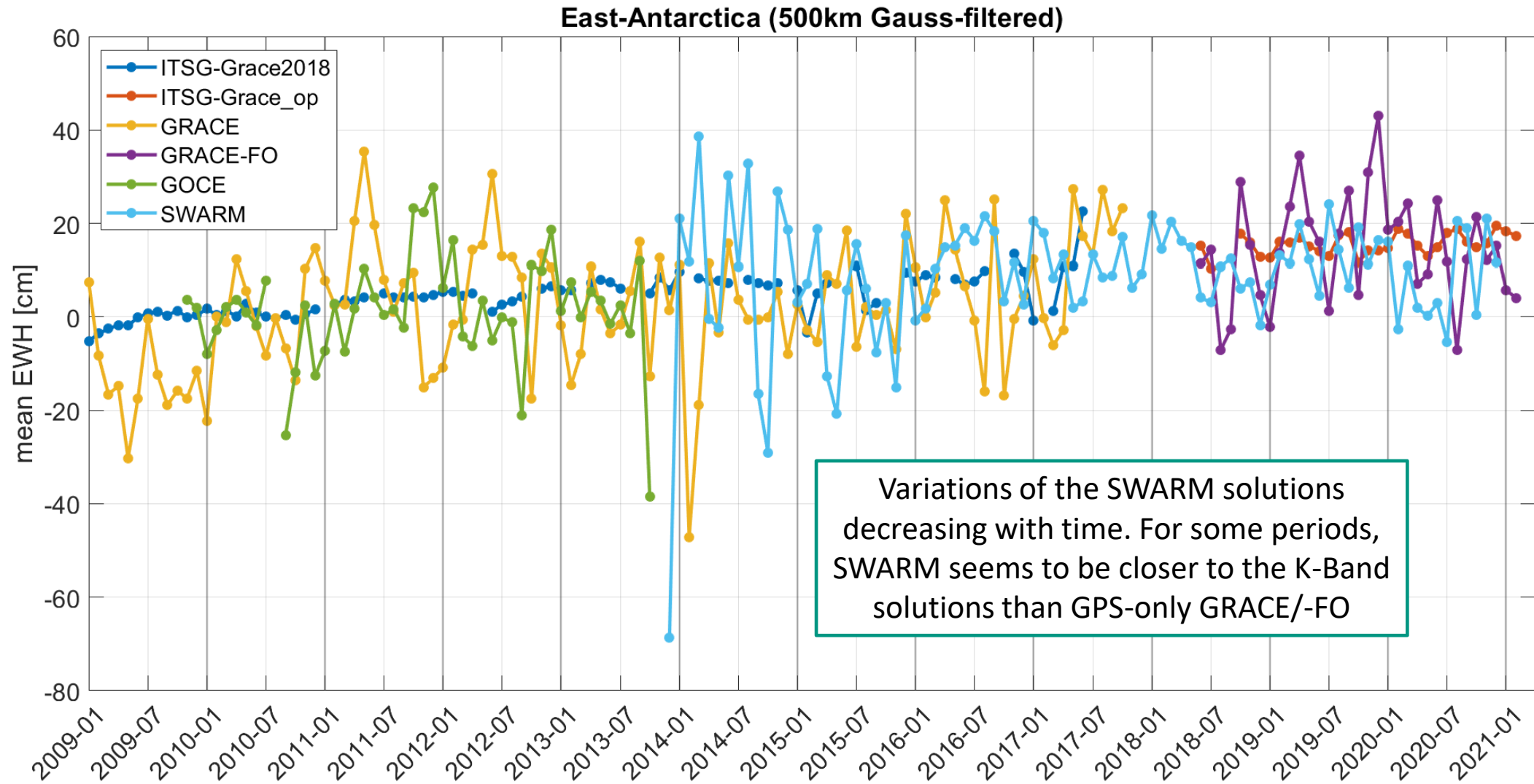
# Evaluation of mass trends and changes: Comparison to other LEOs



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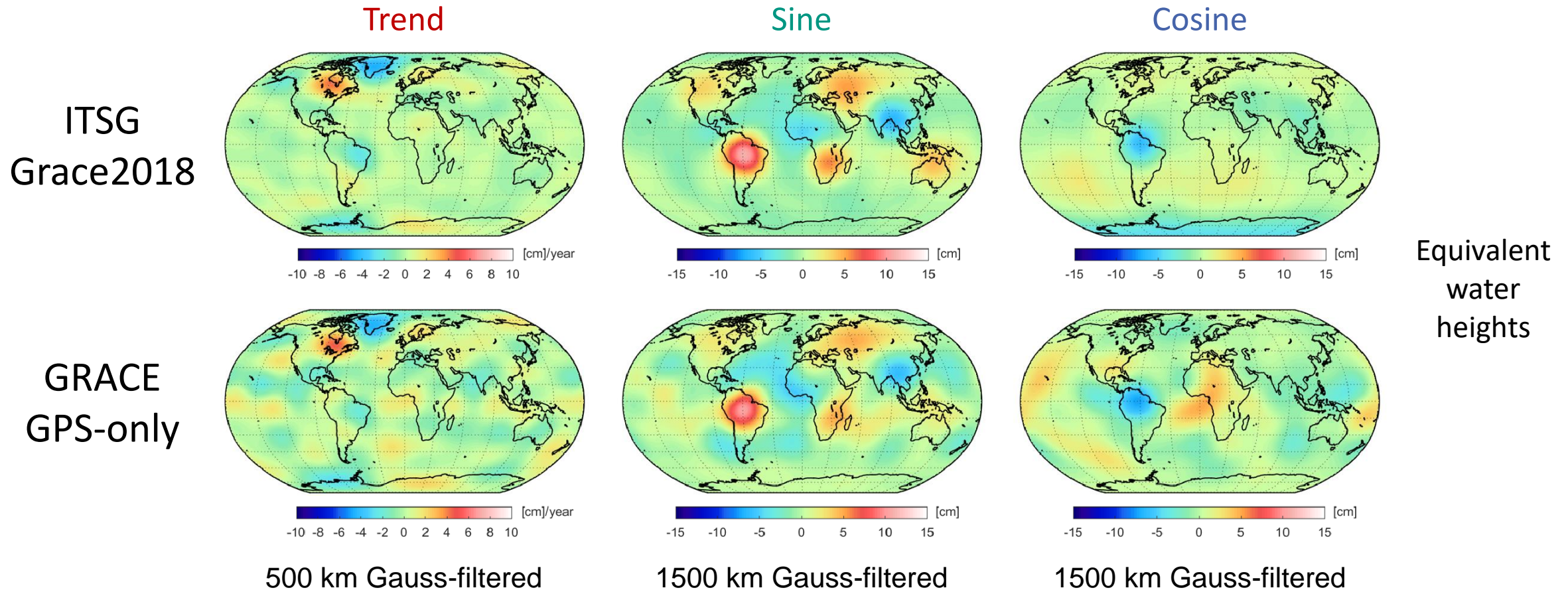


# Evaluation of mass trends and changes: Comparison to other LEOs



# Estimation of trends and annual variations (Jan 2009 – Oct 2017)

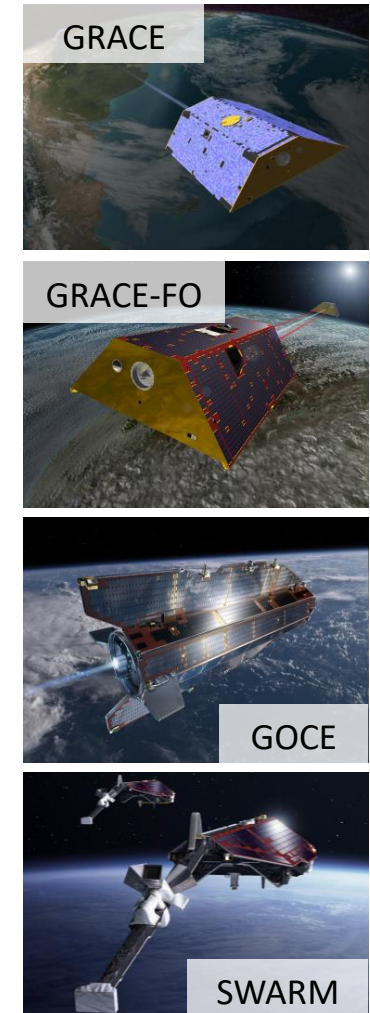
- A posteriori fit of monthly gravity field solutions (up to d/o 10)





# Summary and Outlook

- Time-variable gravity field recovery from kinematic LEO positions
- Processing of time series of monthly gravity field solution from
  - 8.8 years of GRACE GPS data (2009/01 – 2017/10)
  - 2.8 years of GRACE-FO GPS data (2018/06 – 2021/02)
- Major mass trends and changes in Greenland, Antarctica and the Amazon river basin are in good agreement with those derived from inter-satellite ranging (however: as expected GPS-only solutions exhibit larger variations)
- Comparisons to time series based on GOCE and SWARM GPS data are promising in the view of future combinations
- Next steps
  - Extension of the monthly GRACE and GRACE-FO time series
  - Combined time series based on kinematic orbits of multiple LEO satellites



Source: ESA, NASA

# References

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Arnold D, Grombein T, Schreiter L, Sterken V, Jäggi A (2021): Reprocessed precise science orbits and gravity field recovery for the entire GOCE mission (Publication in preparation)

Dahle C, Arnold D, Jäggi A (2017): Impact of tracking loop settings of the Swarm GPS receiver on gravity field recovery. Advances in Space Research 59(12):2843–2854, DOI:10.1016/j.asr.2017.03.003

Mayer-Gürr T, Behzadpur S, Ellmer M, Kvas A, Klinger B, Strasser S, Zehentner N (2018): ITSG-Grace2018 - Monthly, Daily and Static Gravity Field Solutions from GRACE. GFZ Data Services, DOI: 10.5880/ICGEM.2018.003